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Defects in Heavily Phosphorus-Implanted Si Observed after Drive-in Process

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Ion implantation is one of the useful methods to deposit impurities into the surface of semiconductors because of the advantage that any quantity of impurity can be deposited uniformly. However, when phosphorus is heavily doped by ion implantation and thermal drive-in process is followed, growth of many induced defects are usually observed. In the case of planar structure, not only high density dislocation networks are observed within the implanted area but dislocations which propagate laterally outside the implanted area are also observed[1]. The latter dislocations are called "emitter edge dislocations" in the bipolar transistor structure, and give deleterious effects on the transistor characteristics.

We have studied about the processing factors which affected the growth of these defects in phosphorus-implanted samples, and compared with thermally phosphorus-deposited samples. Possible factors we initially considered were total phosphorus concentrations, drive-in conditions(temperature and atomosphere), presence of implantation-genarated primary defects, and initial phosphorus concentration profiles.

Si wafers were (111) oriented, p type 10Ω·cm resistivity. Phosphorus implantation energy was varied from 25keV to 180keV, and ion doses were from $10^{15}/cm^2$ to $3x10^{16}/cm^2$. Thermal deposition was performed using $POCl_3$ source at the temperature between 1050°C and 1150°C. Temperature of drive-in process was also varied from 1000°C to 1200°C. Defects were observed by the transmission electron microscopy, X-ray diffraction topography and chemical etching.

Some important results obtained from our experiments are as follows.

1. "Emitter edge dislocations" appeared only after oxidizing drive-in process and they were remarkable in wet O_2 atomosphere. These dislocations and dislocation networks were observed in the samples of relatively low phosphorus concentration (above $5x10^{15}/cm^2$), whereas, in thermally deposited samples, no defect was observed after oxidizing drive-in process even at the phosphorus concentration of $4x10^{16}/cm^2$. Drive-in in nonoxidizing atomosphere(dry N_2 or dry Ar) generated no "emitter edge dislocations" even in the $3x10^{16}/cm^2$ phosphorus implanted sample. Dislocation networks were observed near the surface, but they were confined within the implanted region and they seemed not to traverse the junction. Dislocation networks and "emitter edge dislocations" observed by transmission electron microscopy is shown in Fig.1.

2. Presence of primary defects lowered the threshold phosphorus concentration above which induced defects were observed to grow. Si ions were implanted into the thermally phosphorus-deposited samples to generate primary defects at the energy of 50keV and doses from $10^{14}/cm^2$ to $1.5x10^{16}/cm^2$. After drive-in in wet O_2 atomosphere at $1100^{\circ}C$, dislocation networks and "emitter edge dislocations" were observed around the patterns implanted above $10^{15}/cm^2$ Si ions. Results of chemical etching of this case are shown in Fig.2.

3. Anomalous compressive strain was observed by the X-ray diffraction topography around phosphorus doped region in oxidized samples which showed "emitter edge dislocations". Whereas, in samples drived-in in nonoxidizing atomosphere, usual tensile strain was observed. This anomalous strain is supposed to have the important effect upon the generation of "emitter edge dislocations". Schwuttke reported the anomalous compressive strain observed in the thermally phosphorus diffused samples[2)] and he speculated that the anomalous strain might relate to the excess phosphorus near the surface. In our case, the excess phosphorus is not the main origin of the compressive strain. In the sample of Fig.2, tensile strain was observed before etching in the left side pattern and compressive strain was observed in the right side pattern. Presence of primary defects and oxidation process seem to have important relation to the generation of the compressive strain.

References

1) N. Yoshihiro et al, 5th Symposium on Ion Implantation in Semiconductors, Feb.,1974, Inst. Phys. Chem. Res.

2) J. M. Fairfield and G. H. Schwuttke, J. of the Electrochem. Soc., Vol.115, No.4, 415 (1968)

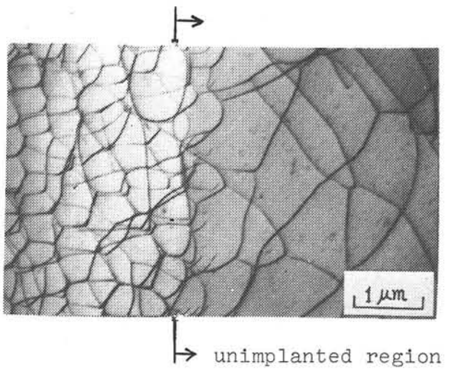

Fig.1 Transmission electron micrograph of induced defects in the sample phosphorus-implanted(25kev, $3x10^{16}/cm^2$) and oxidized($1100^{\circ}C$, 5min., in wet O_2)

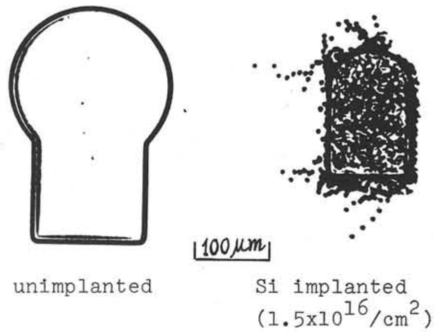

Fig.2 Sirtl etching result of the sample thermally phosphorus-deposited($2.2x10^{16}/cm^2$), Si implanted and oxidized($1100^{\circ}C$, 40min., in wet O_2)